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AURORAL BOUNDARY INDEX FROM 1983 TO 1990

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AIR FORCE SYSTEMS COMMAND

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GEOPHYSICS LABORATORY

HANSCOM AFB, MA 01731-5000

GEOPHYSICS LABORATORY

"This technical report has been reviewed and is approved for publication"

FOR THE COMMANDER

E.G. MULLEN
Branch Chief

RITA SAGALYN
Division Director

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Since the release of the auroral boundary index for the DMSP/F2 satellite equivalent midnight auroral equatorward boundaries have been routinely processed for the DMSP/F6,/F7,/F8 and /F9 satellites at the Air Force Geophysics Laboratory. The auroral equatorward boundary selection algorithm was modified from that for the SSJ/3 particle detector on the /F2 satellite to work for the next generation SSJ/4 instrument that flies on the later satellites. The final product presented here is comprised of a series of solar rotation plots, stacked five per page for the period 1 January 1983 to 15 May 1990. The equivalent midnight boundaries that are plotted are a subset of the complete data base. Only those boundaries occurring in the evening sector are used since there is little ambiguity in their selection. In addition, we apply other criteria that are somewhat satellite dependent. The original set of criteria used on the boundaries from the /F6 and /F7 satellites were modified when boundaries from /F8 and /F9 satellites became available. Since all plots of boundaries that made their way to the public before 1988 used the 'original' criteria, both 'original' and 'modified' criteria will be explained.

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1. INTRODUCTION

It has long been known that increased auroral activity, as indicated by many ionospheric and magnetospheric parameters, such as brightness of auroral arcs, disturbances in the magnetic field, magnitude of the convection electric field and magnitude of field aligned currents, is accompanied by the expansion of the auroral oval. The regularity of the expansion as a function of magnetic activity has been determined by many researchers. A recent review is given by *Feldstein and Galperin* (1985). This, in conjunction with the near circularity of the auroral region, allows an instantaneous crossing of the equatorward auroral boundary to be used, in turn, to indicate auroral activity, as well as to monitor changes in the auroral oval position.

Although the auroral equatorward boundary, when drawn in geomagnetic coordinates, is nearly circular for all levels of auroral activity, its center is offset from the magnetic pole toward the postmidnight local time sector. The offset is a function of magnetic activity. Therefore, individual boundary measurements made for the same auroral activity, but at different local times will differ, and, as such, cannot be directly scaled to auroral activity without removing the local time variation. Removal of the local time variation is reasonably easy to accomplish by statistically determining the position of the auroral oval for every local time sector as a function of some magnetic activity index, such as KP.

A statistical study determining the regression coefficients for a linear fit of equatorward auroral boundaries to KP values was performed for 13 of the 24 hourly local time sectors by *Gussenhoven et al.* (1981). They identified equatorward auroral boundaries by hand, using precipitating electron measurements made onboard the DMSP/F2 satellite. A follow-on study developed a boundary selection algorithm and increased the data base to 20 of 24 local time sectors *(Gussenhoven et al.*, 1983). This study took advantage of the fact that the DMSP/F2 satellite precessed slowly from its original sun-synchronous alignment to cover more local time regions than a strictly sun-synchronous orbit would. The results were presented as a tabular listing of the regression coefficients, A and B, for each magnetic local time hourly interval, T.

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The linear equation is:

$$L_T = A_T + B_T \cdot KP, \tag{1}$$

where L_T is the corrected geomagnetic latitude of the auroral equatorward boundary in the local time sector, T, for magnetic activity, KP.

In all local time sectors the magnetic latitude of the boundary anticorrelates with KP. Some anticorrelations are much higher than others. In the evening and midnight sectors the boundaries are most easily chosen without ambiguity and the anticorrelations with KP are almost always highest here, at about 0.8 or above. The correlation becomes progressively worse as one proceeds post-midnight to noon. Some early morning correlations would probably be high, but the DMSP orbit either does not reach the auroral positions here, or cuts the oval very obliquely, obscuring the boundary determination. By the time the noon sector is reached the electron diffuse aurora is often severely depleted and patchy, again making boundary selection difficult. Often in the post noon sector the first boundary to be encountered when the satellite is traveling poleward is the cusp boundary. The dynamics of the cusp boundary cannot be interchanged with those of the diffuse aurora. Using the statistical results for A_T and B_T in Eq. 1, the auroral boundary taken at any local time can be scaled to one local time. The time variation of this *scaled* boundary will give a time history of the variation of auroral activity. We labelled the *scaled* boundary the *equivalent midnight boundary.*

2. CALCULATING THE EQUIVALENT MIDNIGHT BOUNDARY

A computer algorithm, adjusted for each new satellite-detector pair flown, automatically selects the equatorward auroral boundary four times during each DMSP 100-minute orbit: twice crossing the instantaneous north pole auroral oval, and twice crossing the instantaneous south pole auroral oval. The algorithm returns the position of the boundary, L, in corrected geomagnetic latitude (MLAT), the hourly magnetic local time sector, T, in which the boundary is located, and the universal time, t, that the boundary was observed. Other ephemerides can also be attached to the boundary file by means of t.

For a boundary, $L_T(t)$, in magnetic local time sector T, a projected KP, called KP^*, can be determined using the linear regression coefficients, A_T, B_T, in Eq. 1:

$$KP^*(t) = [L_T(t) - A_T] / B_T. \tag{2}$$

The original boundary at T can now be projected to the midnight sector using KP^* in Eq. 1 and the regression values for the midnight sector T = 00:

$$L_{00}^*(t) = A_{00} + (B_{00}/B_T) \times (L_T(t) - A_T). \tag{3}$$

$L_{00}^*(t)$ is the equivalent midnight auroral boundary, and the set of values as a function of time constitutes the auroral boundary index.

3. THE REGRESSION COEFFICIENTS AND ORIGINAL CRITERIA FOR THE AURORAL BOUNDARY INDEX

The auroral equatorward boundaries are automatically selected and form a data base from which the regression coefficients can be continuously updated. In this section we describe the way in which we apply regression coefficients and edit the data base to provide the most reliable, continuous auroral boundary index. In Section 5 we present the auroral boundary index from 1983 to 1990. The data are taken from four DMSP satellites whose characteristics and times of operation are given in Table 1. Copies of the same particle detector were flown on each of these satellites. A description of the detector and the calibration of the instruments is given in *Schumaker et al.* (1989). The detectors on these four satellites are designated the SSJ/4 detectors and are an upgraded version of the SSJ/3 detectors used in the original boundary studies. The SSJ/4 detectors have a larger energy range and include ion, as well as electron, measurements.

The number of boundaries chosen by the boundary selection algorithm from the data taken aboard each satellite is given in Table 2. The regression coefficients, A and B, for each local time sector determined from the entire boundary data set represented in Table 2 are given in Table 3. The original criteria for creating the auroral boundary index were a) to use only evening boundaries, and b) to use magnetic local time zones for which the negative of the boundary correlation with KP was greater than 0.75. Application of these criteria to the data in Table 3 means that only boundaries in the local time zones from 18-19 to 23-24 MLT are used to create the auroral boundary index.

Figure 1 shows the equivalent midnight auroral equatorward boundary for a 12-day period in 1989 when the boundary is calculated using data points from all magnetic local time sectors, that is, without applying any selection criteria. We make two observations: 1) There are a considerable number of bad points, that is, points that are impossibly high or impossibly low in magnetic latitude. In almost every case these points occur in an isolated fashion. The high latitude false boundaries often result from encounters with the cusp population when the diffuse aurora is severely diminished on the dayside. The low latitude false boundaries have a variety of causes including noise spikes. 2) There is considerable oscillation from boundary to boundary. This, in large part, is due to differences in projecting the morning and the evening boundaries to midnight. It is also due to differences between successive northern and southern hemisphere boundaries.

Applying the original criteria on the boundaries to determine the auroral activity index makes most of the non-physical boundaries disappear. The equivalent midnight boundaries for the same 12-day period used in Figure 1 after applying the selection criteria are shown in Figure 2. In addition to removing the obvious extreme boundaries, the data is decimated by about a factor of two. The oscillation from boundary to boundary is reduced, but not removed entirely. Any boundaries at this point that still 'looked' bad are checked by examining survey plots of the data for the orbit in question. Non-physical points are hand-edited out. This occurs less than once per solar rotation. Table 4 shows the statistics on the boundaries used in the auroral activity index using the original criteria.

TABLE 1 CHARACTERISTICS OF THE DMSP SATELLITES		
Satellite	Time of Operation	Orbit Plane
DMSP/F6	Nov 1982 to Jul 1987	Dawn-Dusk
DMSP/F7	Nov 1983 to Jan 1988	Noon-Midnight
DMSP/F8	Jul 1987 to Present	Dawn-Dusk
DMSP/F9	Jan 1988 to Present	Dawn-Dusk

TABLE 2 BOUNDARY STATISTICS			
Satellite	Total Boundaries	Total Days	Average Number/Day
DMSP/F6	74804	1646	45.45
DMSP/F7	63808	1463	43.61
DMSP/F8	48642	1012	48.07
DMSP/F9	39461	827	47.72

TABLE 3

REGRESSION COEFFICIENTS OF AURORAL EQUATORWARD BOUNDARIES VS KP ALL BOUNDARIES, 1983-1990

Magnetic Local Time	Number of. Boundaries	Intercept A_T	Slope B_T	Correlation Coefficient
00-01	2349	67.57	-1.62	-0.73
01-02	43	68.31	-1.39	-0.66
02-03	41	68.92	+0.03	+0.03
03-04	2741	67.07	-1.50	-0.56
04-05	12900	66.56	-1.82	-0.76
05-06	20682	67.28	-1.79	-0.78
06-07	16186	68.10	-1.83	-0.74
07-08	13369	68.17	-1.65	-0.68
08-09	17422	68.98	-1.58	-0.67
09-10	17873	69.13	-1.24	-0.56
10-11	6565	68.99	-1.00	-0.46
11-12	2218	68.54	-0.62	-0.30
12-13	1056	68.90	-0.34	-0.16
13-14	1296	70.76	-0.37	-0.18
14-15	1564	71.48	-0.63	-0.29
15-16	1785	72.73	-1.12	-0.50
16-17	3332	73.22	-1.46	-0.71
17-18	8193	72.20	-1.48	-0.74
18-19	19946	71.64	-1.64	-0.80
19-20	17347	71.09	-1.85	-0.82
20-21	17539	69.71	-1.66	-0.78
21-22	14175	69.25	-2.07	-0.84
22-23	16234	67.89	-1.88	-0.83
23-24	11205	67.18	-1.75	-0.81

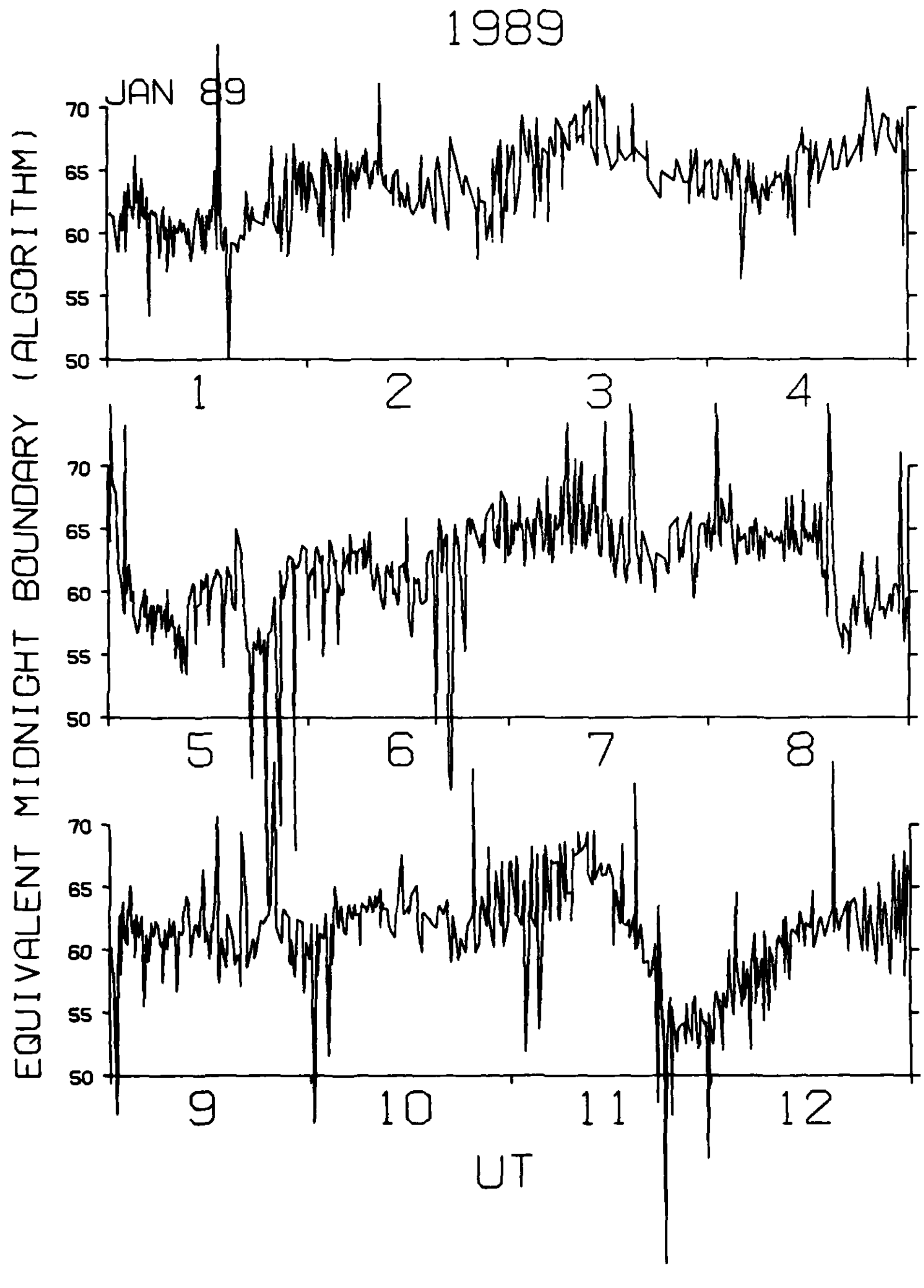


Figure 1. Midnight equivalent auroral boundary created by using all boundary crossings and the regression coefficients in Table 3

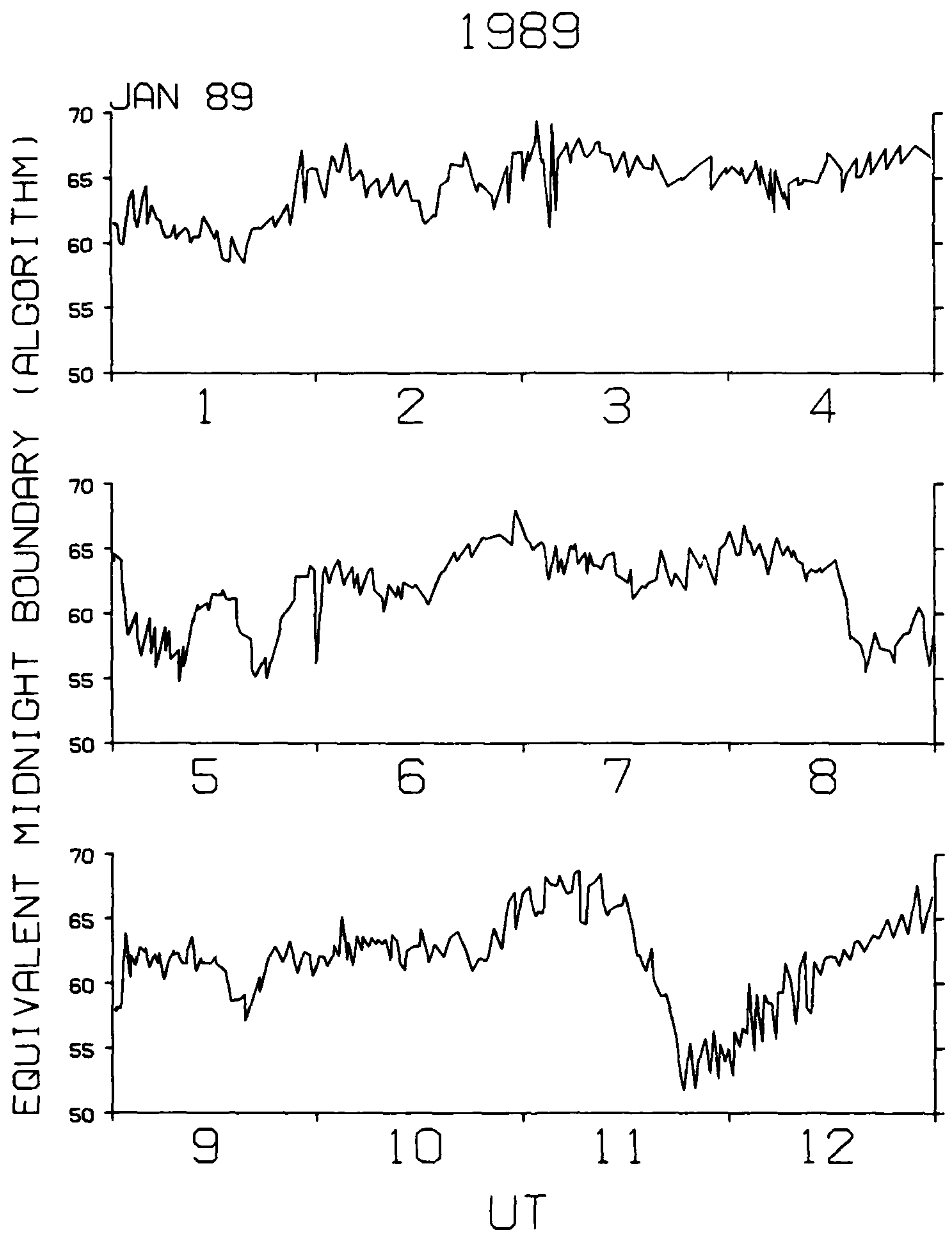


Figure 2. Same as Figure 1 using the original criteria for creating the auroral boundary index, that is, evening boundaries and the regression coefficients in Table 3

TABLE 4

BOUNDARY STATISTICS AFTER APPLYING ORIGINAL SELECTION CRITERIA

Satellite	Total Boundaries	Total Days	Average Number/Day
DMSP/F6	29098	1646	17.68
DMSP/F7	30475	1461	20.86
DMSP/F8	17638	1012	17.43
DMSP/F9	19536	827	23.62

4. THE REGRESSION COEFFICIENTS AND MODIFIED CRITERIA FOR THE AURORAL BOUNDARY INDEX

Because the orbits of the DMSP satellites vary, F6 and F8 having a dawn-dusk orbit plane, and F7 and F9 a noon-midnight orbit plane, they differ both in the frequency of magnetic local time crossings of the boundaries, and how favorable the crossing is for application of the boundary algorithm. A near-parallel crossing of a boundary, particularly one with considerable structure, is an unfavorable crossing. It is also the case that the orbit planes of the satellites are not strictly dawn-dusk and noon-midnight, so there is difference in local time coverage by hemisphere as well. Table 5 lists the regression coefficients for the magnetic local times most frequently sampled by satellite and by hemisphere. If one chooses only those local time bins for which the correlation coefficient is better than -0.75, as before, from which to create the auroral boundary index, then the set of boundaries used by satellite and by hemisphere will be those listed in Table 6.

Figure 3 shows the equivalent midnight boundary when the modified criteria are applied for the same time interval as in Figures 1 and 2. We note that in comparing Figures 2 and 3 two questionable boundaries, one on Day 3 and one on Day 6, have been removed. Otherwise there is very little noticeable difference between the two. The boundary statistics used under the modified criteria are given in Table 7, where we show, as well, the average number of boundaries per day that are lost and gained using the new criteria when compared to those using the original criteria. We see that, in general, the net change is less than 10%. For the final plots, hand editing is still done just as the original criteria called for. Again, the editing procedure eliminates less than one boundary per solar rotation.

TABLE 5

REGRESSION COEFFICIENTS OF AURORAL EQUATORWARD BOUNDARIES VS KP, BY SATELLITE AND HEMISPHERE, 1983-1990

DMSP/F6

	NORTHERN HEMISPHERE				SOUTHERN HEMISPHERE			
MLT	# Pts.	A_T	B_T	CC	# Pts.	A_T	B_T	CC
16-17	0	0.00	0.00	0.00	1949	73.05	-1.35	-0.68
17-18	1326	72.39	-1.43	-0.78	2720	71.99	-1.36	-0.69
18-19	5623	71.06	-1.50	-0.81	5118	71.10	-1.53	-0.78
19-20	8085	69.48	-1.44	-0.76	3155	70.59	-1.48	-0.81
20-21	1539	68.96	-0.78	-0.57	0	0.00	0.00	0.00

DMSP/F7

	NORTHERN HEMISPHERE				SOUTHERN HEMISPHERE			
MLT	# Pts.	A_T	B_T	CC	#Pts.	A_T	B_T	CC
18-19	0	0.00	0.00	0.00	1295	70.51	-1.27	-0.69
19-20	0	0.00	0.00	0.00	2070	70.36	-1.69	-0.81
20-21	0	0.00	0.00	0.00	2737	69.55	-1.84	-0.84
21-22	2781	68.43	-1.83	-0.80	3296	68.31	-1.79	-0.82
22-23	5462	68.06	-1.79	-0.83	5124	67.34	-1.81	-0.83
23-24	6815	67.04	-1.72	-0.82	829	67.39	-1.77	-0.85
24-01*	2017	67.32	-1.60	-0.75	0	0.00	0.00	0.00

* *This is considered an evening MLT*

TABLE 5 (CONT)

DMSP/F8

	NORTHERN HEMISPHERE				SOUTHERN HEMISPHERE			
MLT	# Pts.	A_T	B_T	CC	#Pts.	A_T	B_T	CC
17-18	0	0.00	0.00	0.00	1284	73.68	-1.66	-0.76
18-19	1321	72.68	-1.68	-0.82	1821	72.84	-1.73	-0.79
19-20	3319	72.28	-1.81	-0.82	3613	71.67	-1.80	-0.83
20-21	3822	71.28	-2.07	-0.84	1315	71.22	-1.69	-0.78
21-22	4872	69.61	-1.55	-0.75	0	0.00	0.00	0.00
22-23	601	69.34	-0.65	-0.45	0	0.00	0.00	0.00

DMSP/F9

	NORTHERN HEMISPHERE				SOUTHERN HEMISPHERE			
MLT	# Pts.	A_T	B_T	CC	#Pts.	A_T	B_T	CC
17-18	47	67.07	-1.41	-0.72	441	71.86	-1.48	-0.75
18-19	9	65.60	-0.19	-0.14	969	71.86	-1.89	-0.81
19-20	45	66.77	-1.22	-0.65	1435	71.30	-2.11	-0.86
20-21	81	67.94	-1.75	-0.66	1761	70.29	-2.13	-0.85
21-22	3455	69.24	-2.11	-0.84	2503	68.96	-2.16	-0.86
22-23	3510	68.35	-2.06	-0.84	2135	68.04	-1.94	-0.81
23-24	3546	67.35	-1.81	-0.79	15	70.01	-1.42	-0.58

TABLE 6 MAGNETIC LOCAL TIME BINS USED UNDER MODIFIED CRITERIA		
	NORTHERN HEMISPHERE	SOUTHERN HEMISPHERE
Satellite	Magnetic Local Time Interval Taken Counterclockwise	
DMSP/F6	1700 to 2100	1800 to 2000
DMSP/F7	2200 to 0100	1900 to 2400
DMSP/F8	1700 to 2100	1700 to 2000
DMSP/F9	2100 to 2400	1800 to 2300

TABLE 7

BOUNDARY STATISTICS USING MODIFIED CRITERIA

Satellite	Total Boundaries	Total Days	Average# Per Day	#Gained	#Lost	Net
DMSP/F6	28884	1646	17.55	0.81	-0.93	-0.12
DMSP/F7	31209	1461	21.36	1.38	-0.89	+0.49
DMSP/F8	30192	1012	19.95	3.10	-0.19	+2.51
DMSP/F9	19383	827	23.44	0.00	-0.19	-0.19

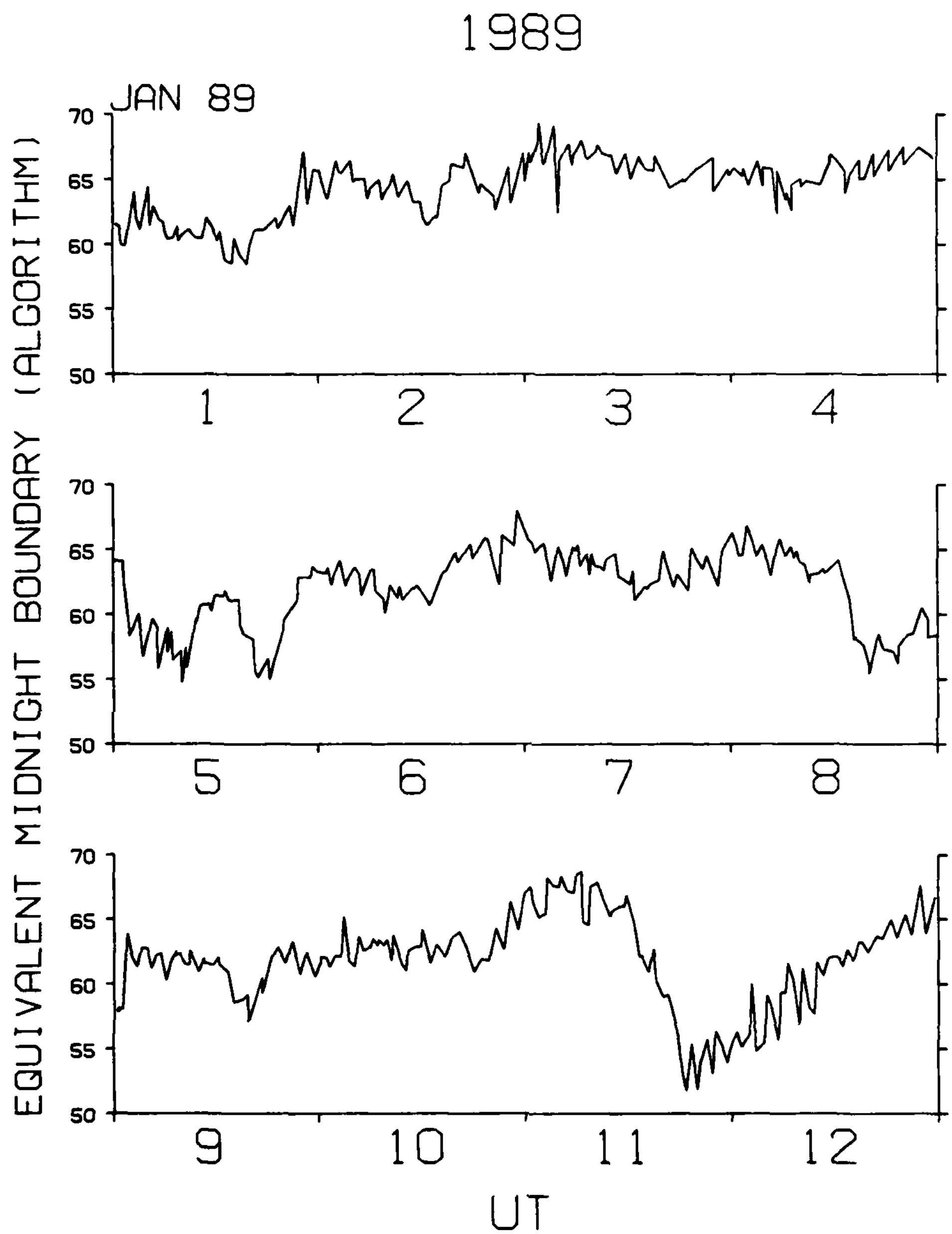


Figure 3. Same as Figure 1 using the modified criteria for creating the auroral boundary index, that is, evening boundaries and the regression coefficients in Table 5

5. THE AURORAL BOUNDARY INDEX FROM 1983 TO 1989

In the 21 pages that follow, the equivalent midnight boundary made under the modified criteria, which we designate the auroral boundary index, is plotted for the period from 1983 to 1990. Some points to note about the boundary plots are the following:

1) The length of the line plot is one solar rotation and uses the same rotation definition as used in the yearly KP 'musical' summaries.

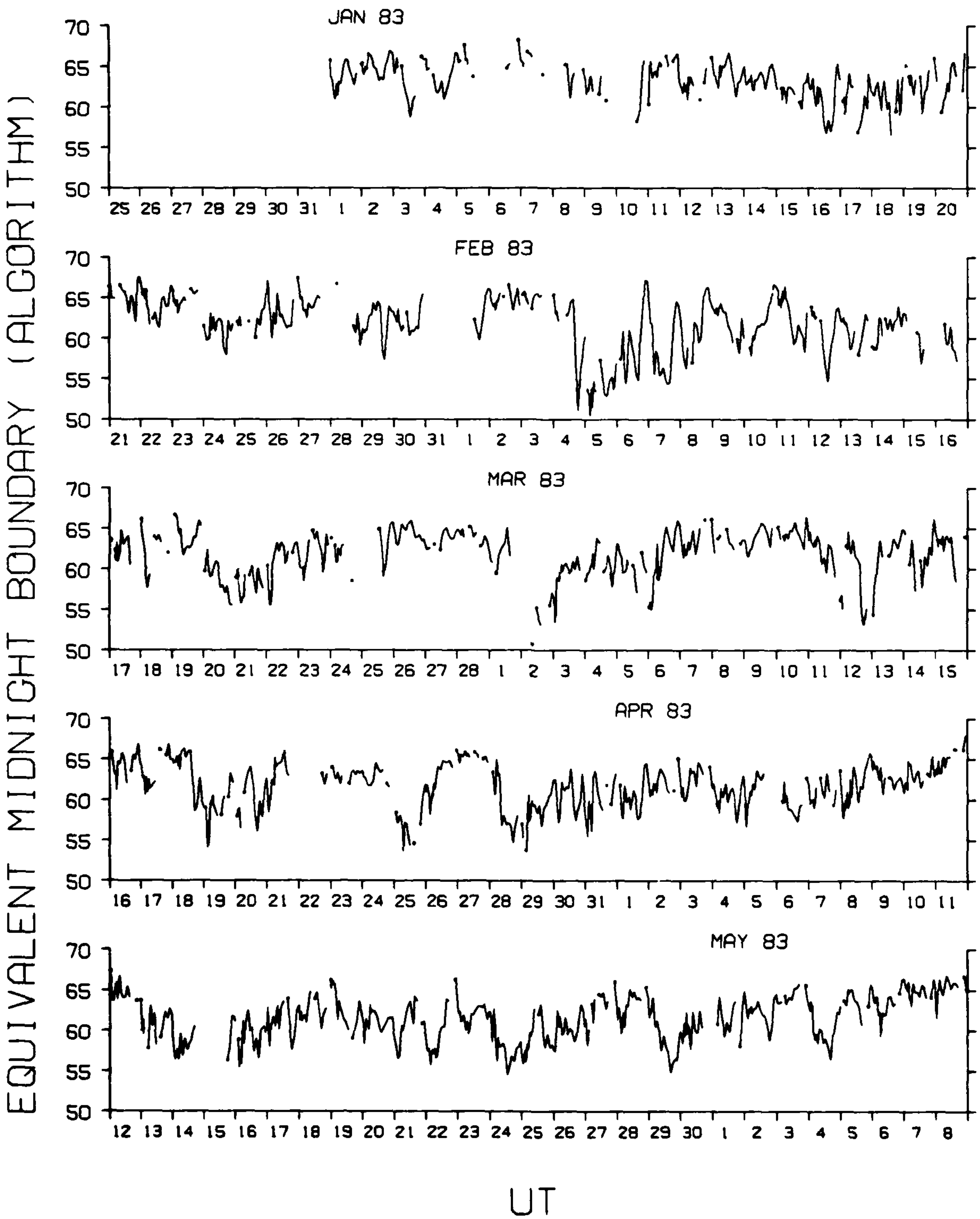
2) A new month is marked near Day 1 for that month. The day of the month is marked on the abscissa within the interval corresponding to that day.

3) In making the plots, the line is discontinued if a gap of greater than two hours occurs in the boundaries. The end of a gap is marked with a dot at the position of the boundary.

4) In routine processing of the DMSP data a lower limit of 45° MLAT is applied. There were two time periods for which the magnetospheric activity was so great that the equatorward auroral boundary went below this cutoff. Special tapes were produced extending the data to lower latitudes. Since most of the criteria developed for the boundary index did not apply, that is, latitudes occurring outside designated high correlation magnetic local time zones, poor statistics for very high KP, etc., the boundaries below 50° were selected by hand and retained only when near midnight. The boundaries were then included in the data base. The two time intervals are 8-9 Feb 1986 and 13-14 Mar 1989.

5) Although listings of the auroral boundary index for the entire period from 1983-1990 are too large to include here, they are on file at the Air Force Geophysics Laboratory and are easy to transition for short periods of time. For the period of CRRES (Combined Release and Radiation Effects Satellite) operations the auroral boundary index will be maintained on the CRRES README file accessible over the SPAN network. CRRES was launched on 25 July 1990. The file will be maintained for a given, as yet unspecified, size, after which earlier data will be dropped for more recent data. Access to the CRRES README file is given in APPENDIX A.

1983


JAN 83
FEB 83
MAR 83
APR 83
MAY 83
EQUIVALENT MIDNIGHT BOUNDARY (ALGORITHM)
70
65
60
55
50
25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
17 18 19 20 21 22 23 24 25 26 27 28 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
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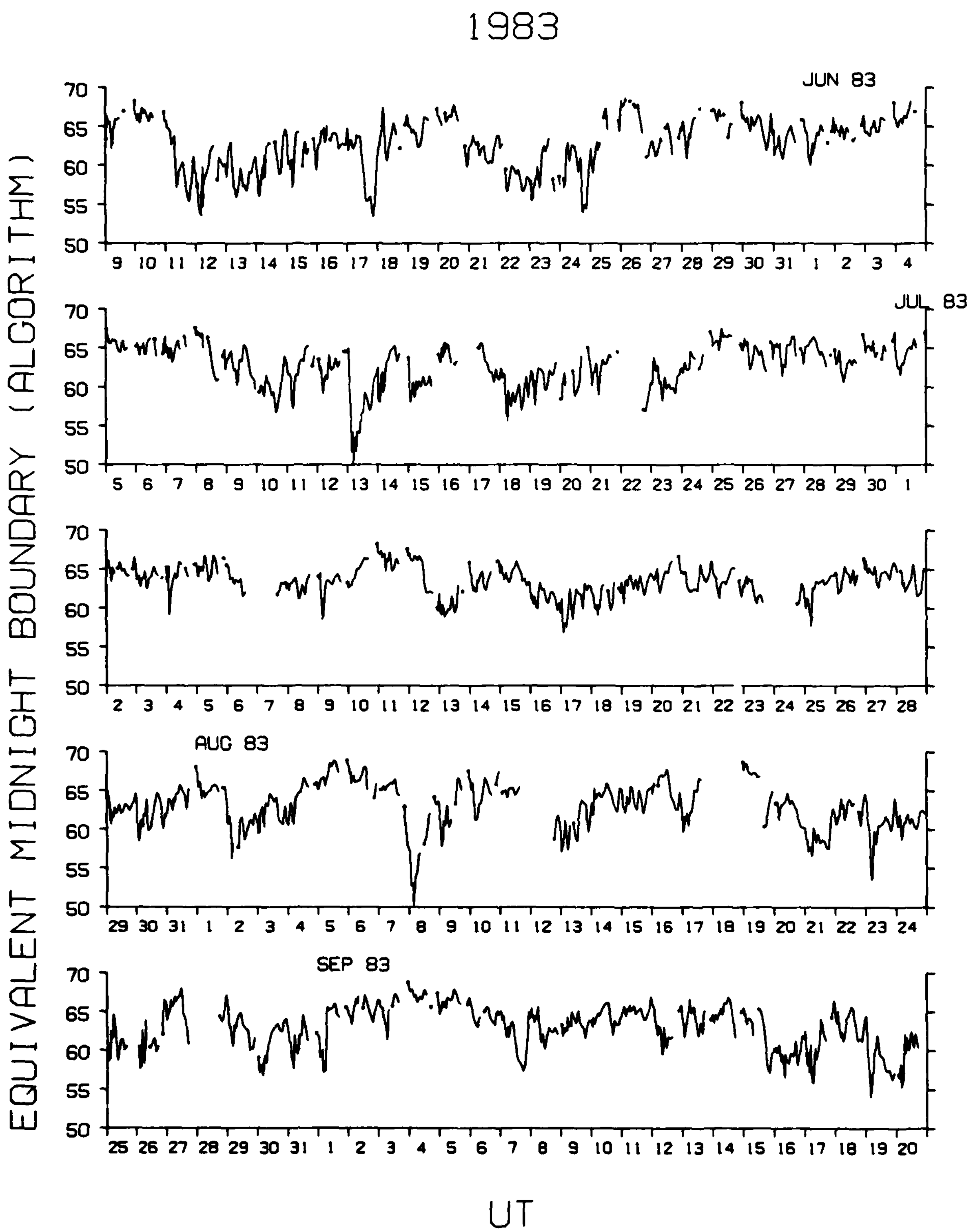
1983
JUN 83
JUL 83
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EQUIVALENT MIDNIGHT BOUNDARY (ALGORITHM)
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4
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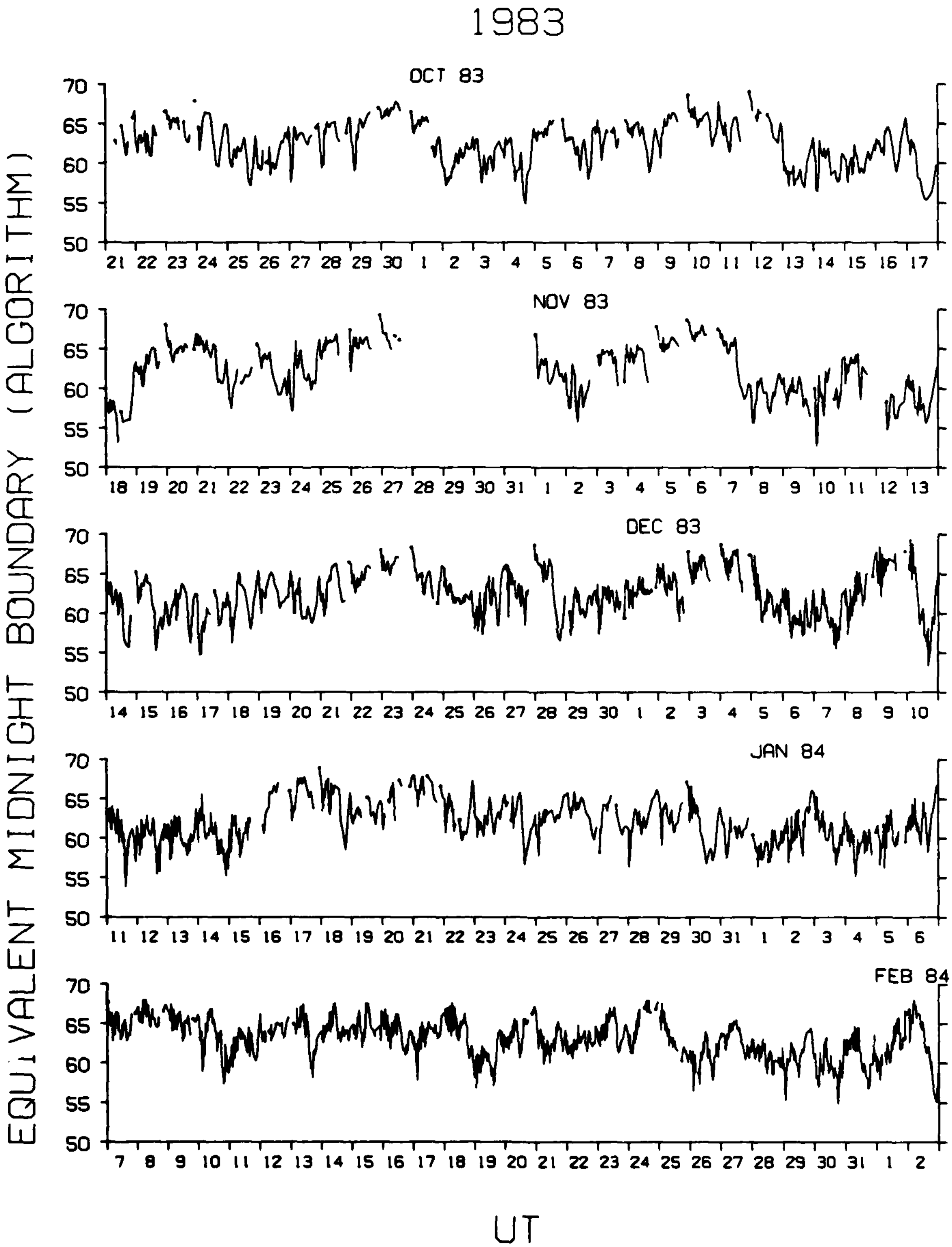
1983
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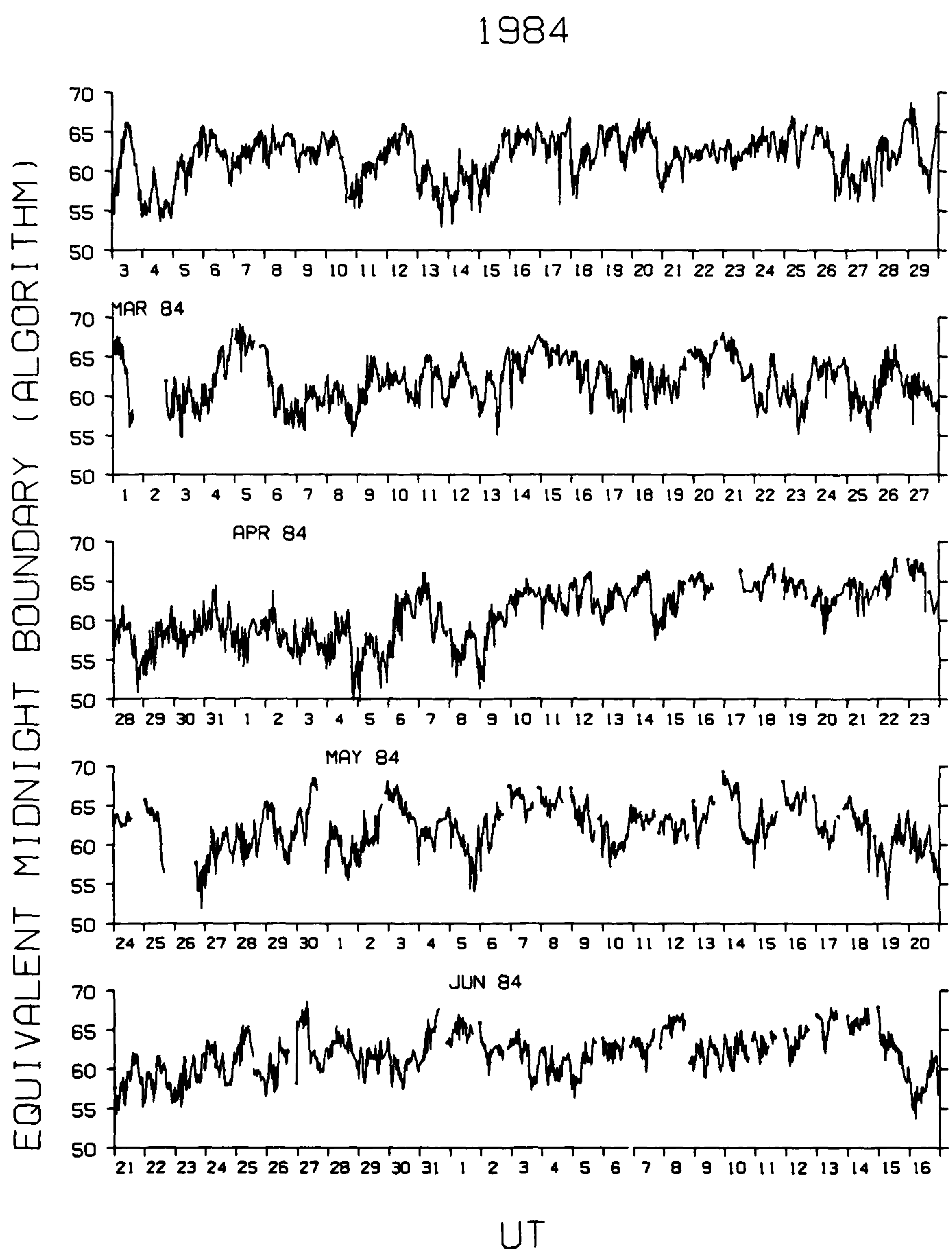
EQUIVALENT MIDNIGHT BOUNDARY (ALGORITHM)
UT


1984
EQUIVALENT MIDNIGHT BOUNDARY (ALGORITHM)
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MAR 84
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APR 84
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MAY 84
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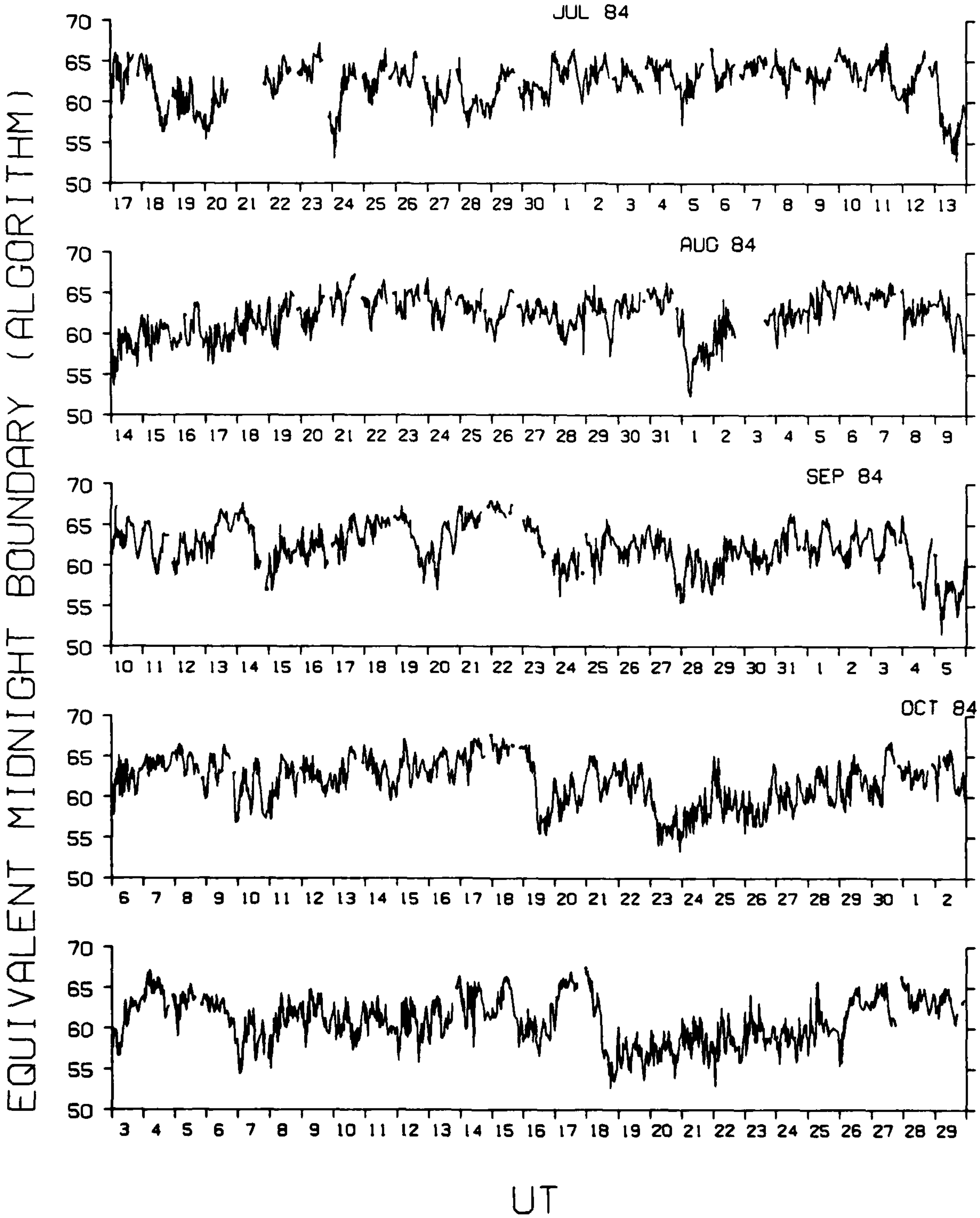
1984



JUL 84
AUG 84
SEP 84
OCT 84
EQUIVALENT MIDNIGHT BOUNDARY (ALGORITHM)
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17 18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8 9 10 11 12 13
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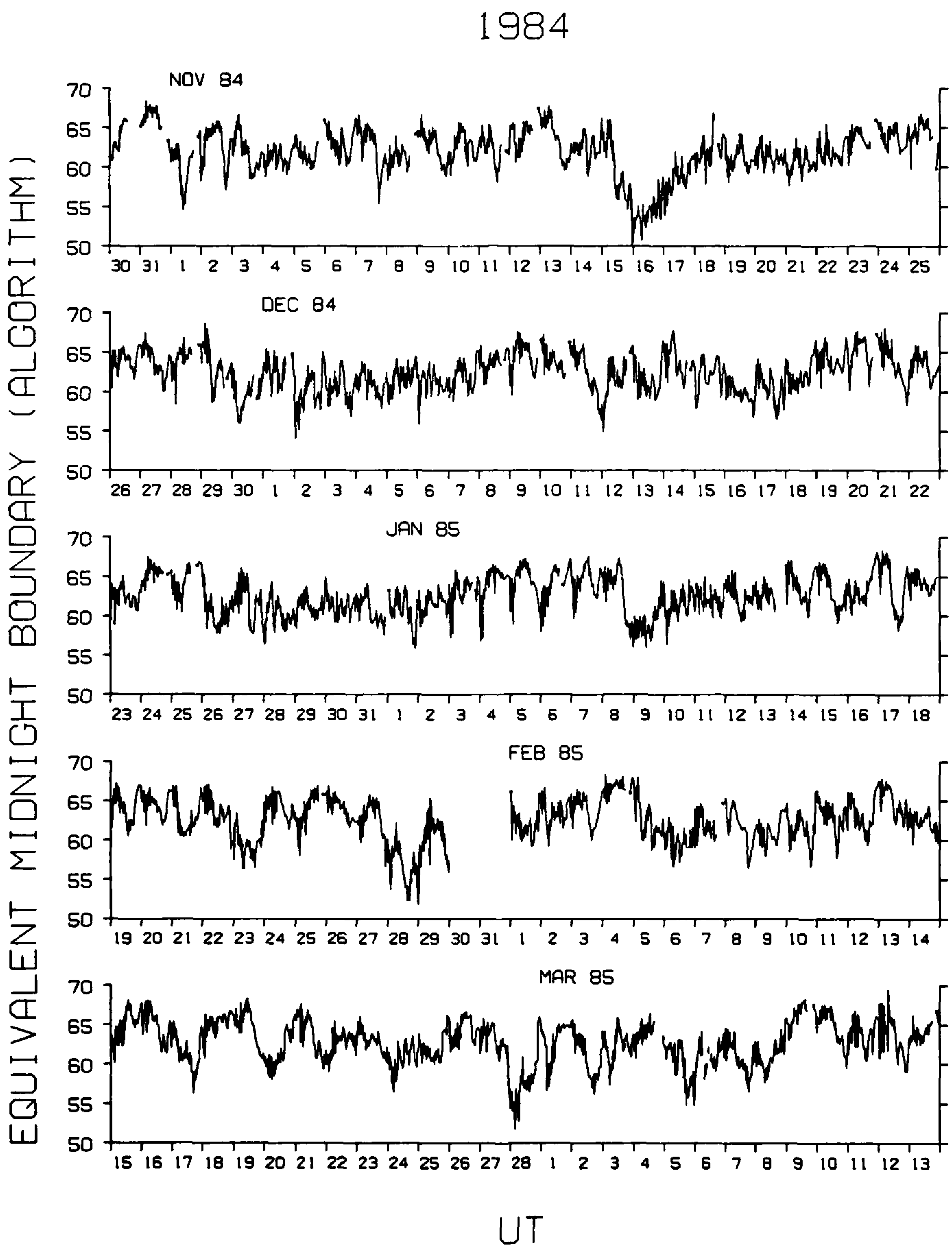
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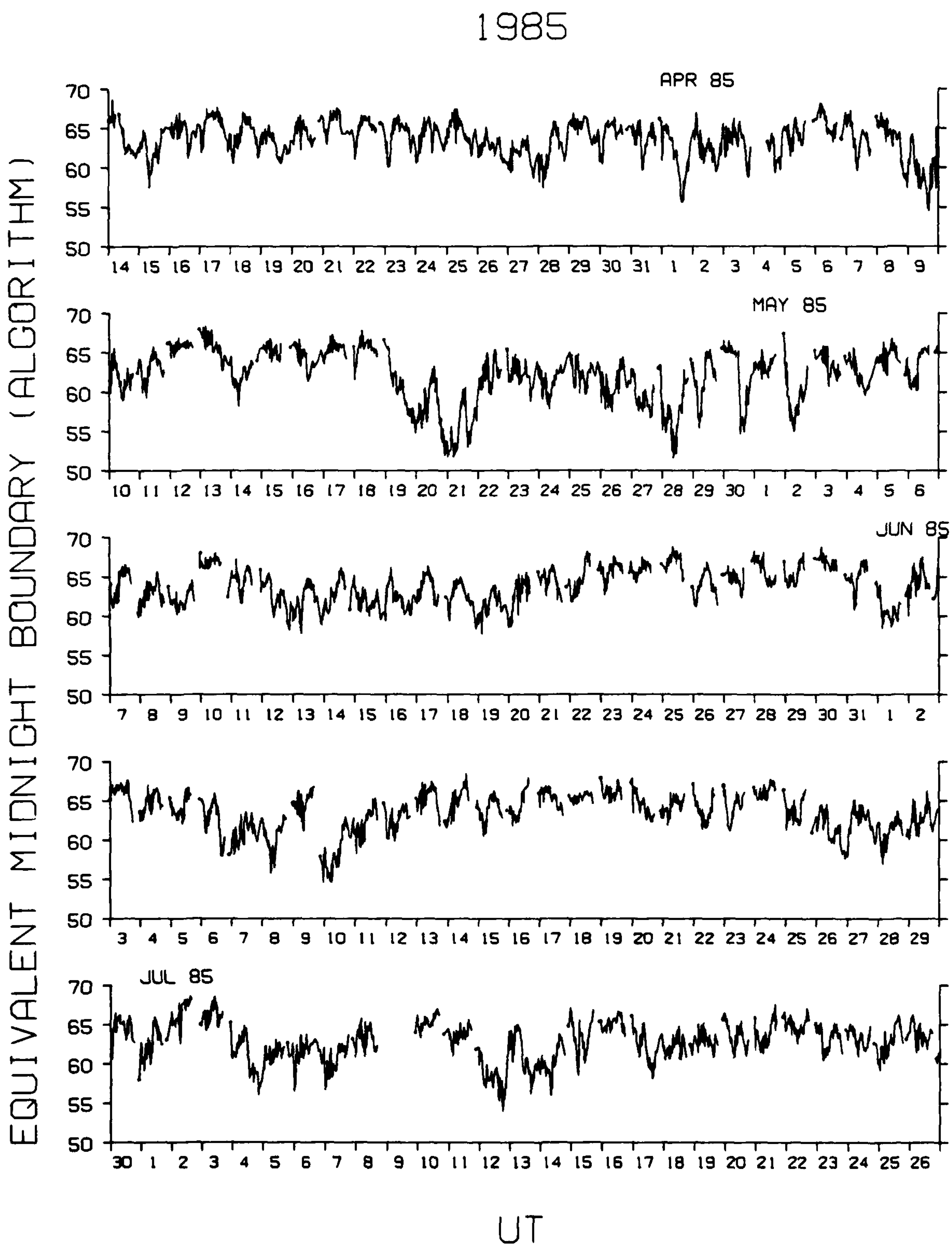
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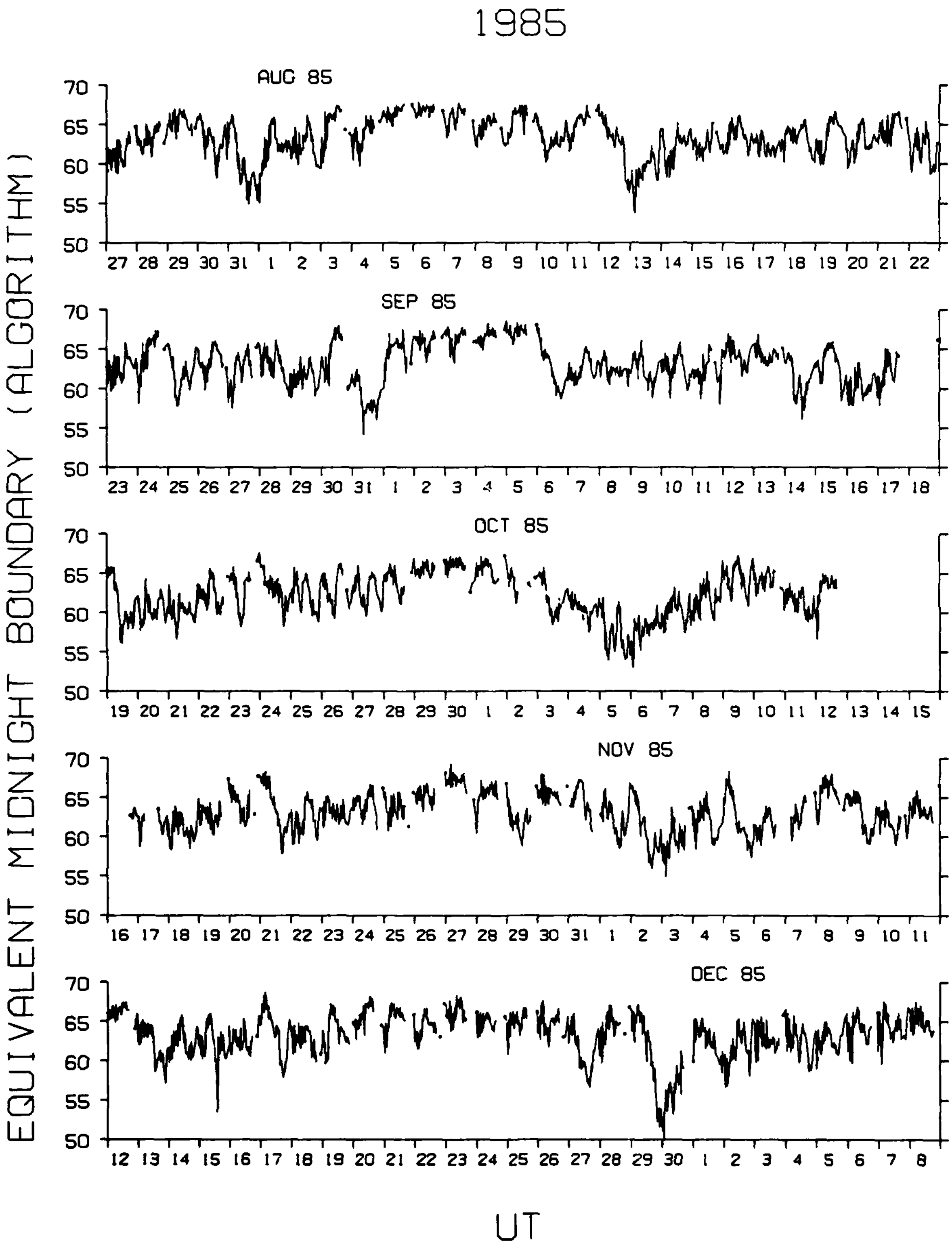

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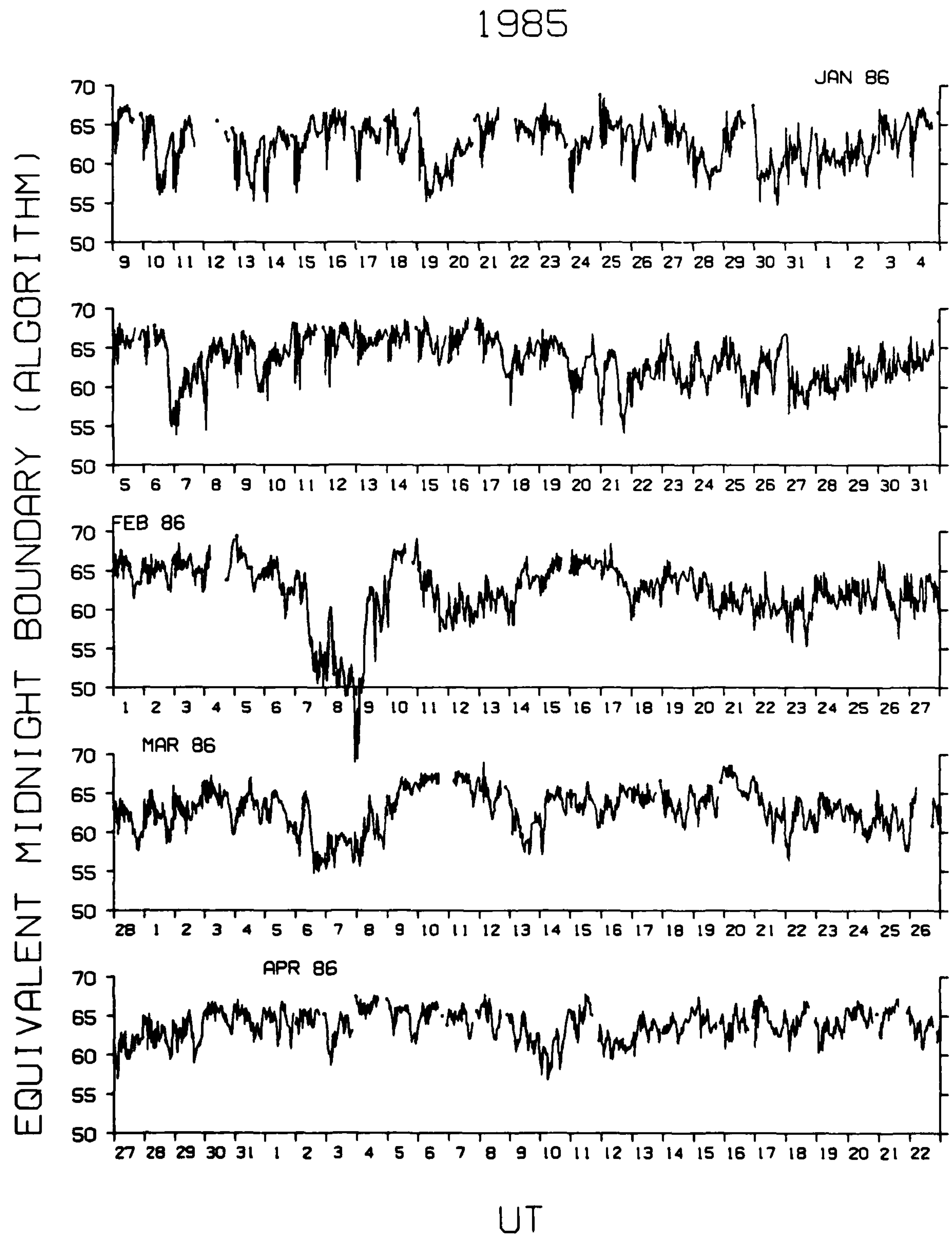
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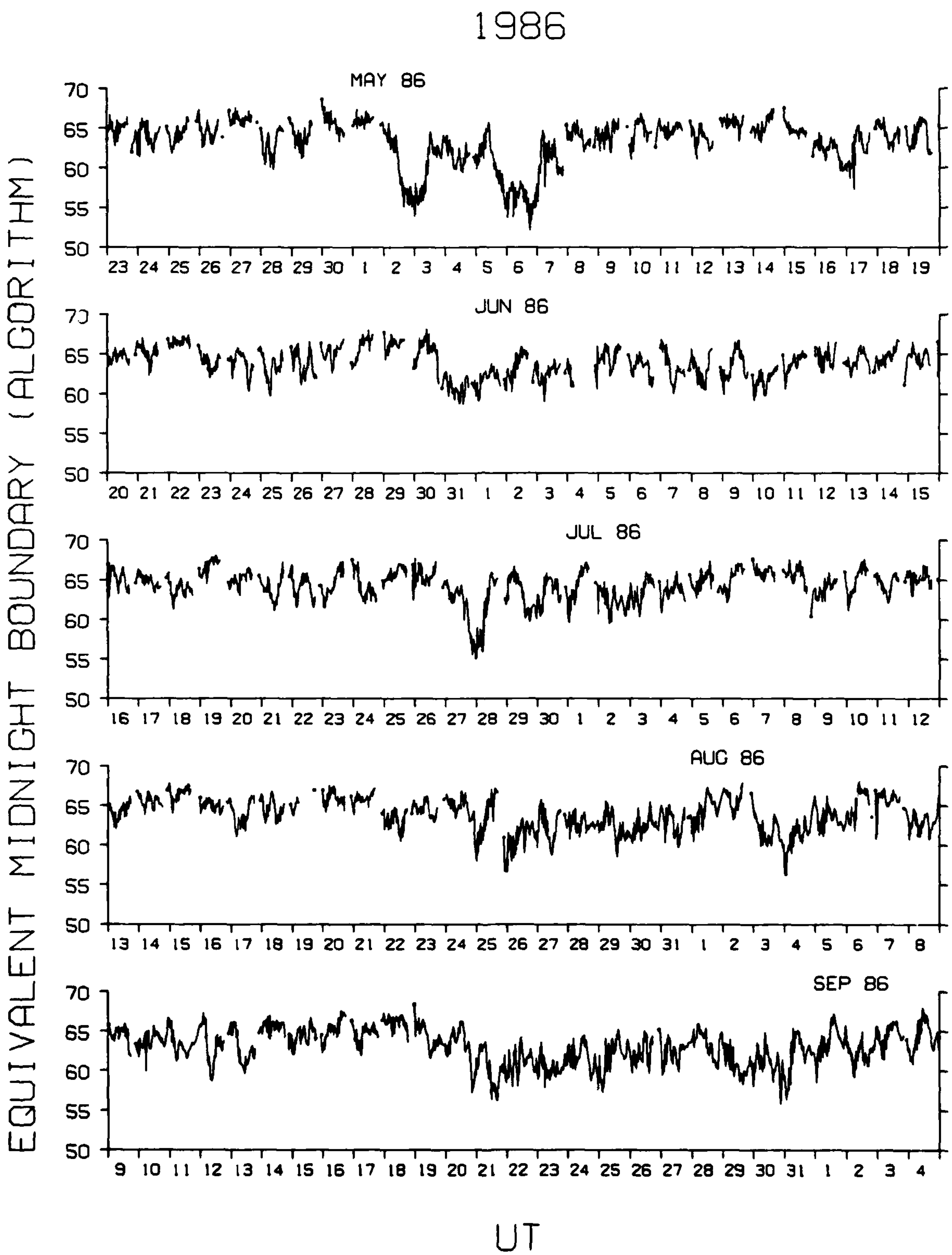
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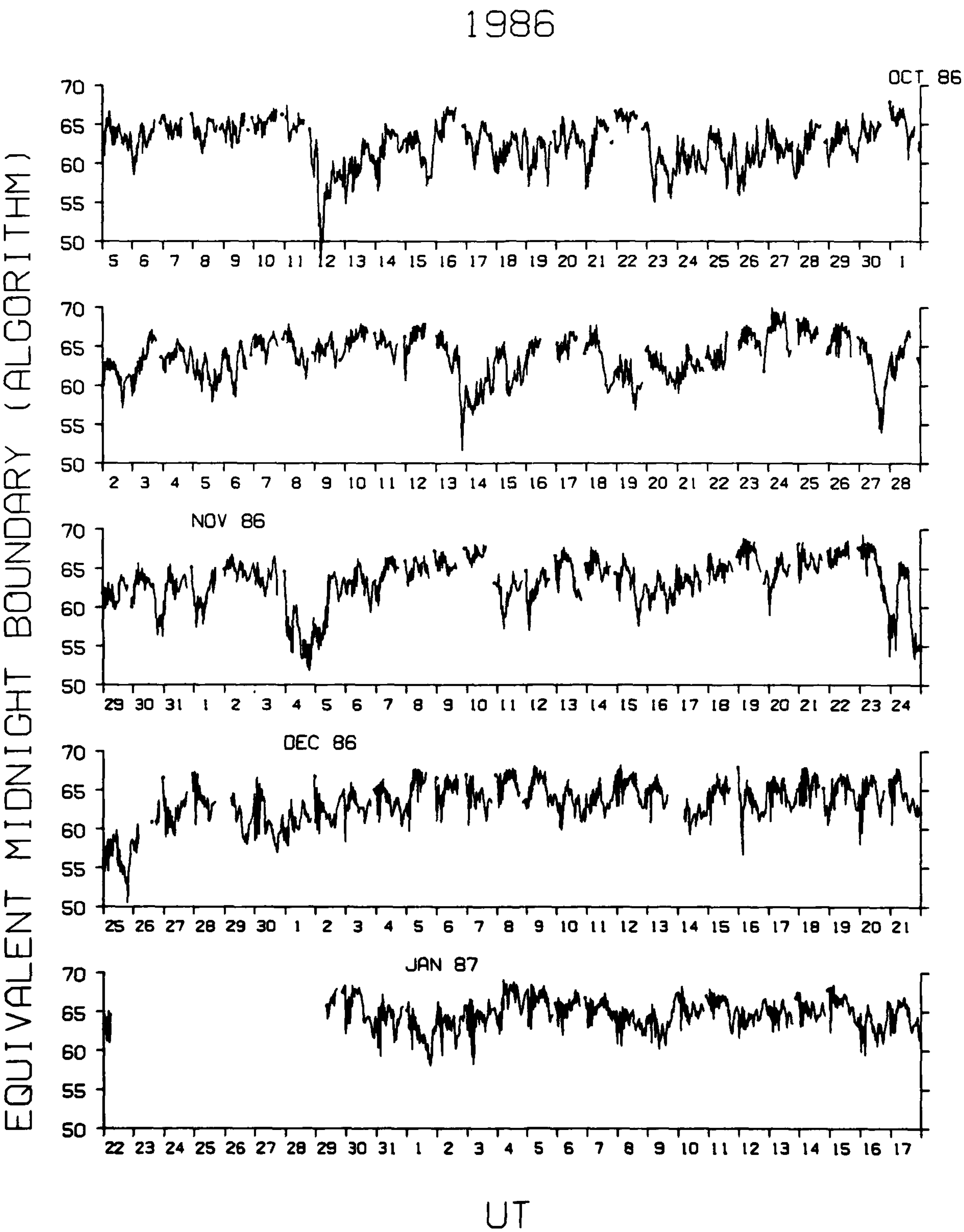
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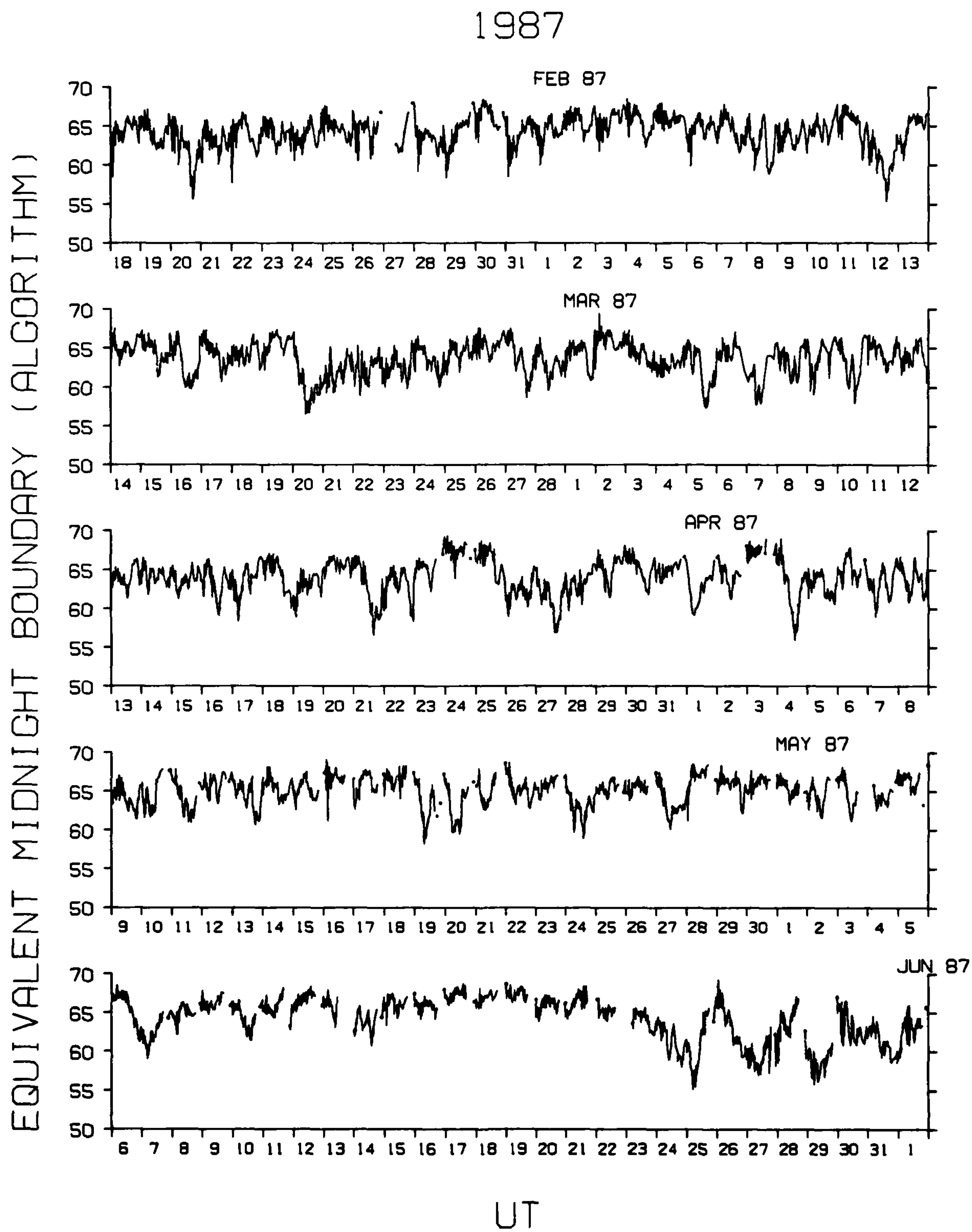
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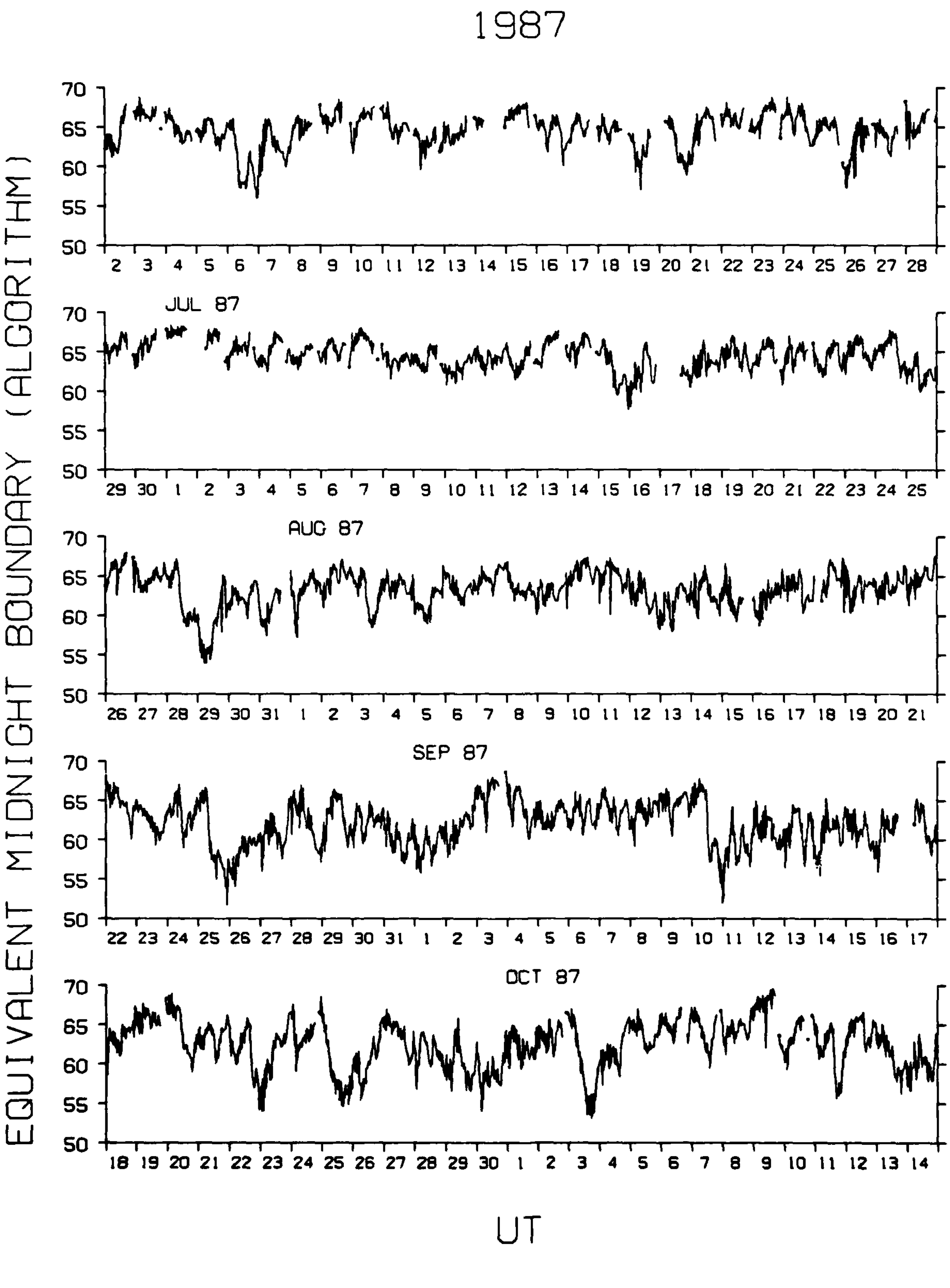
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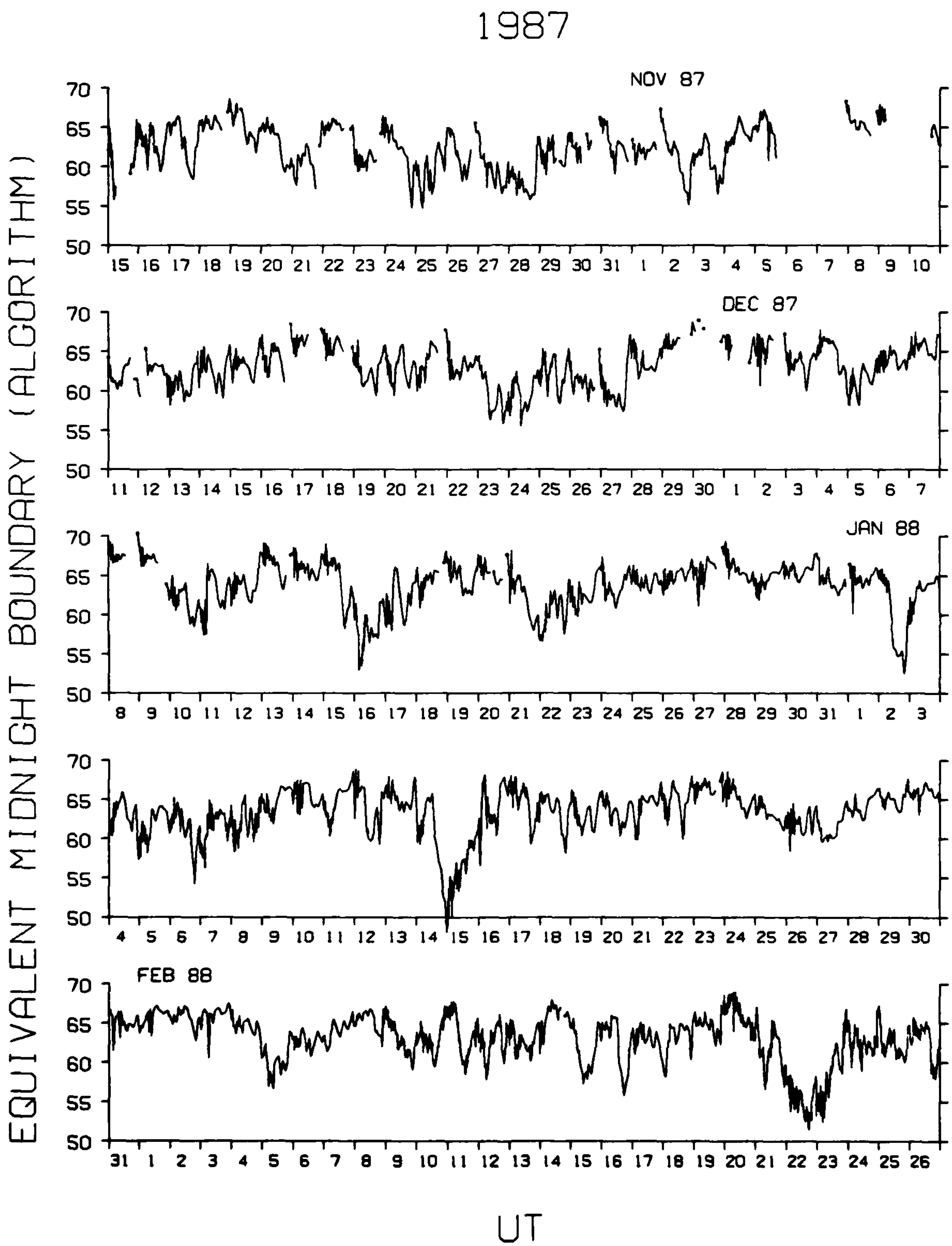
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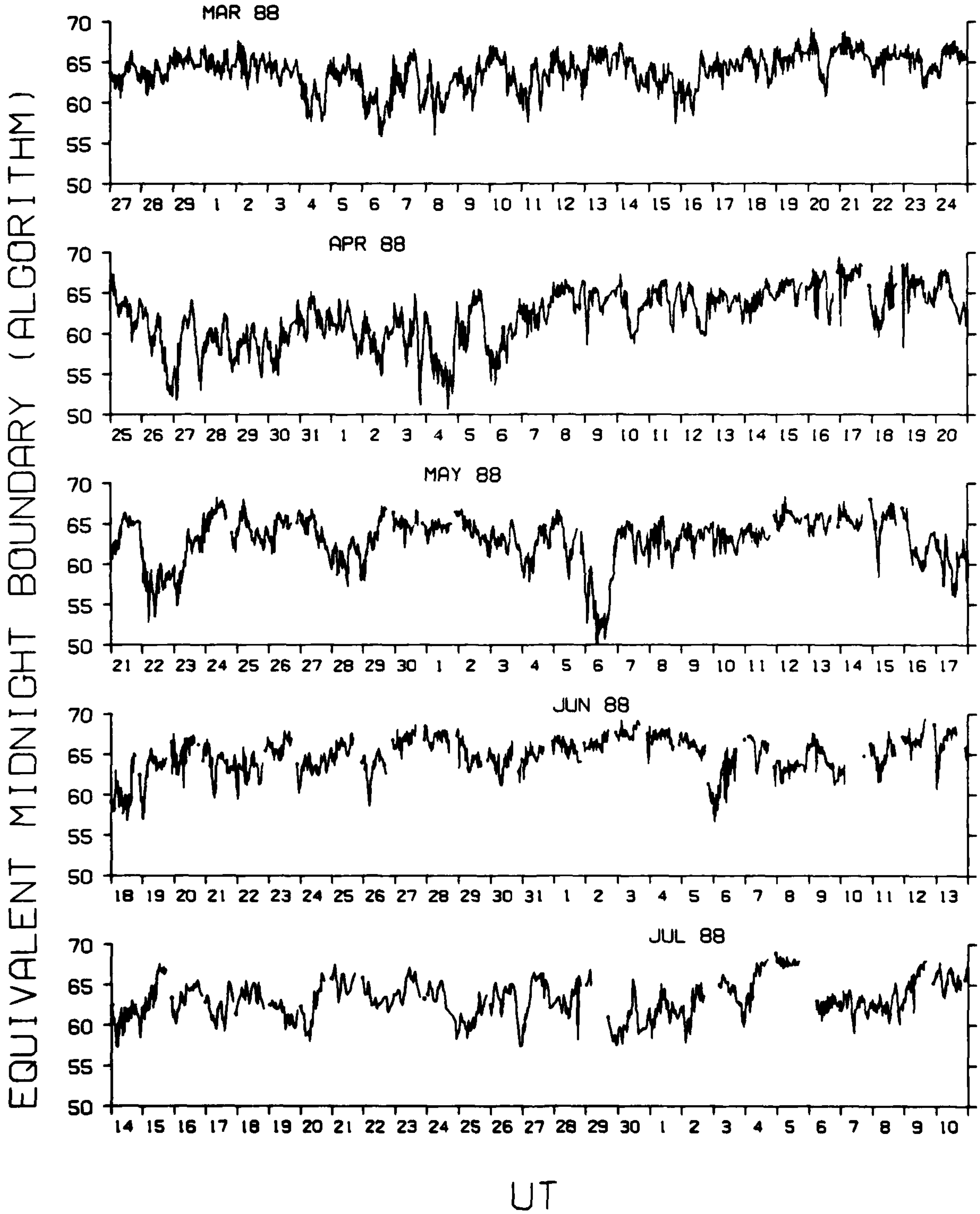
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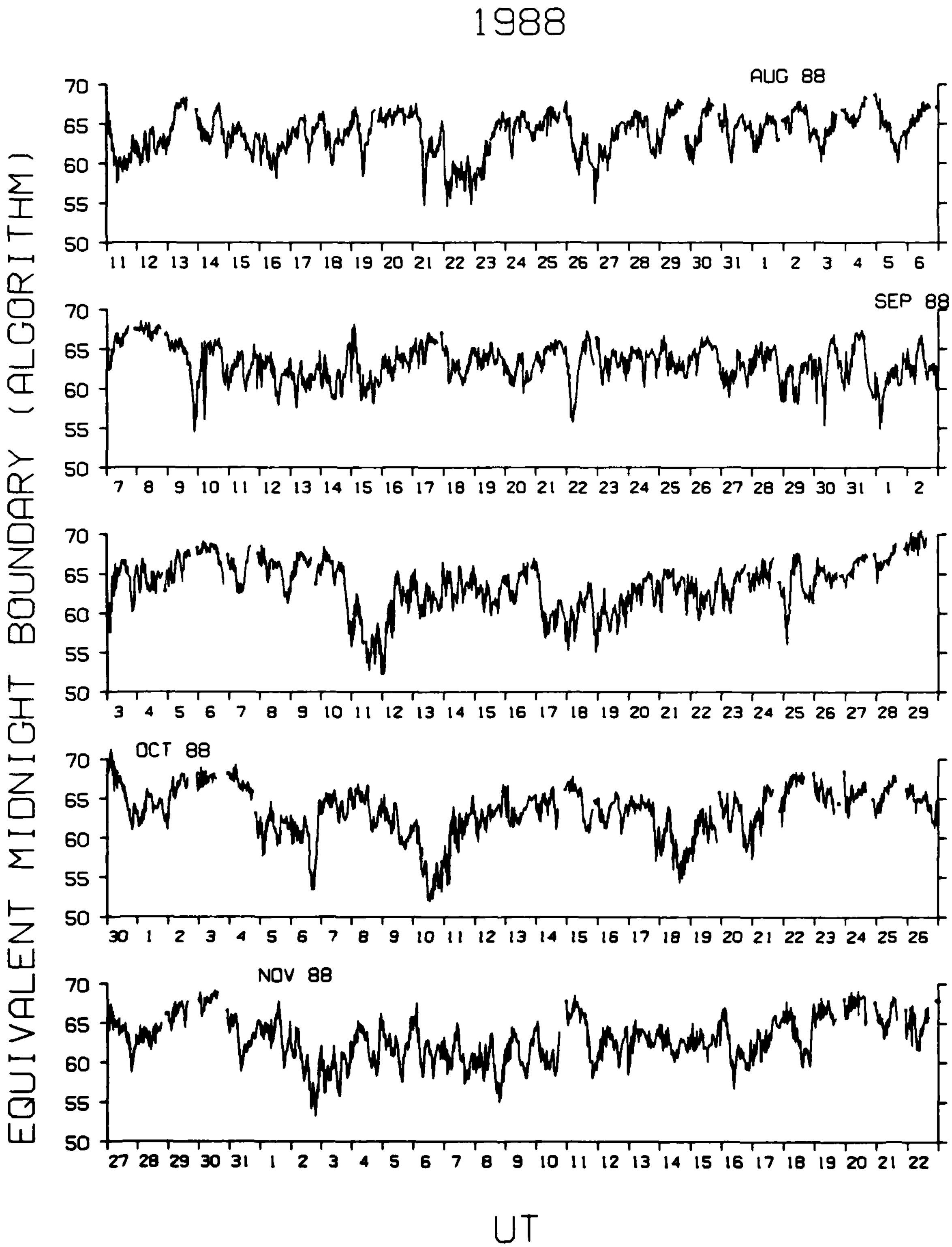
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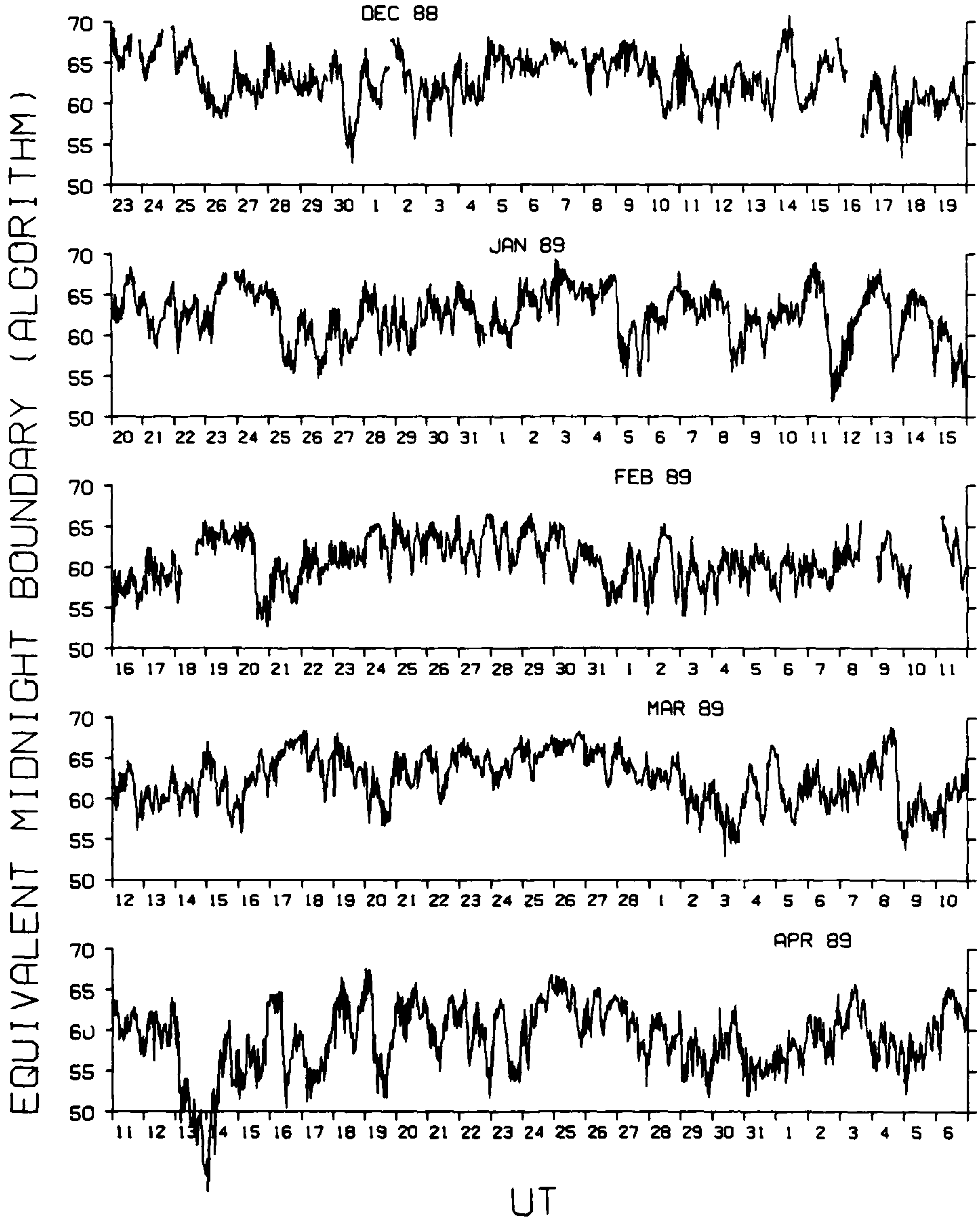

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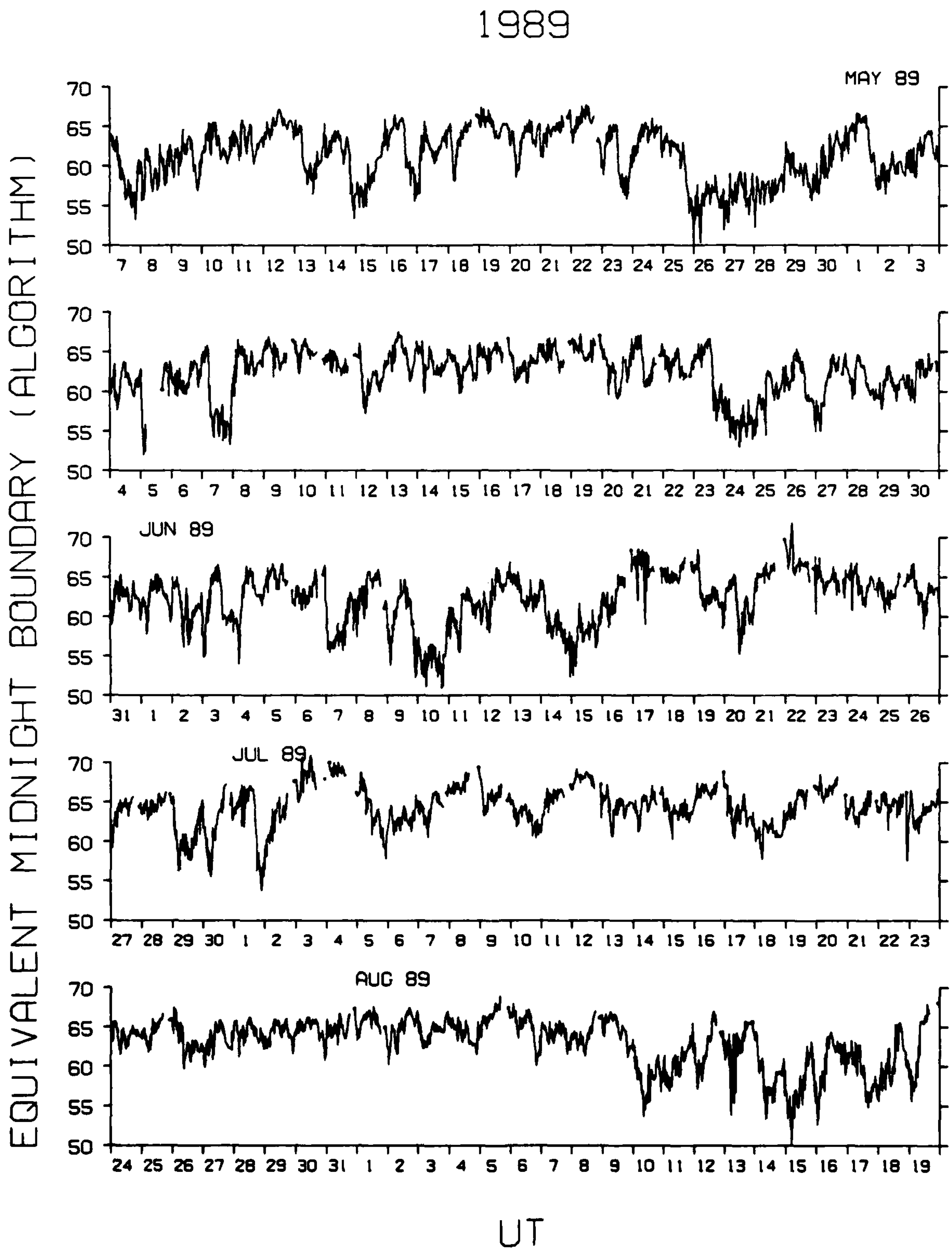

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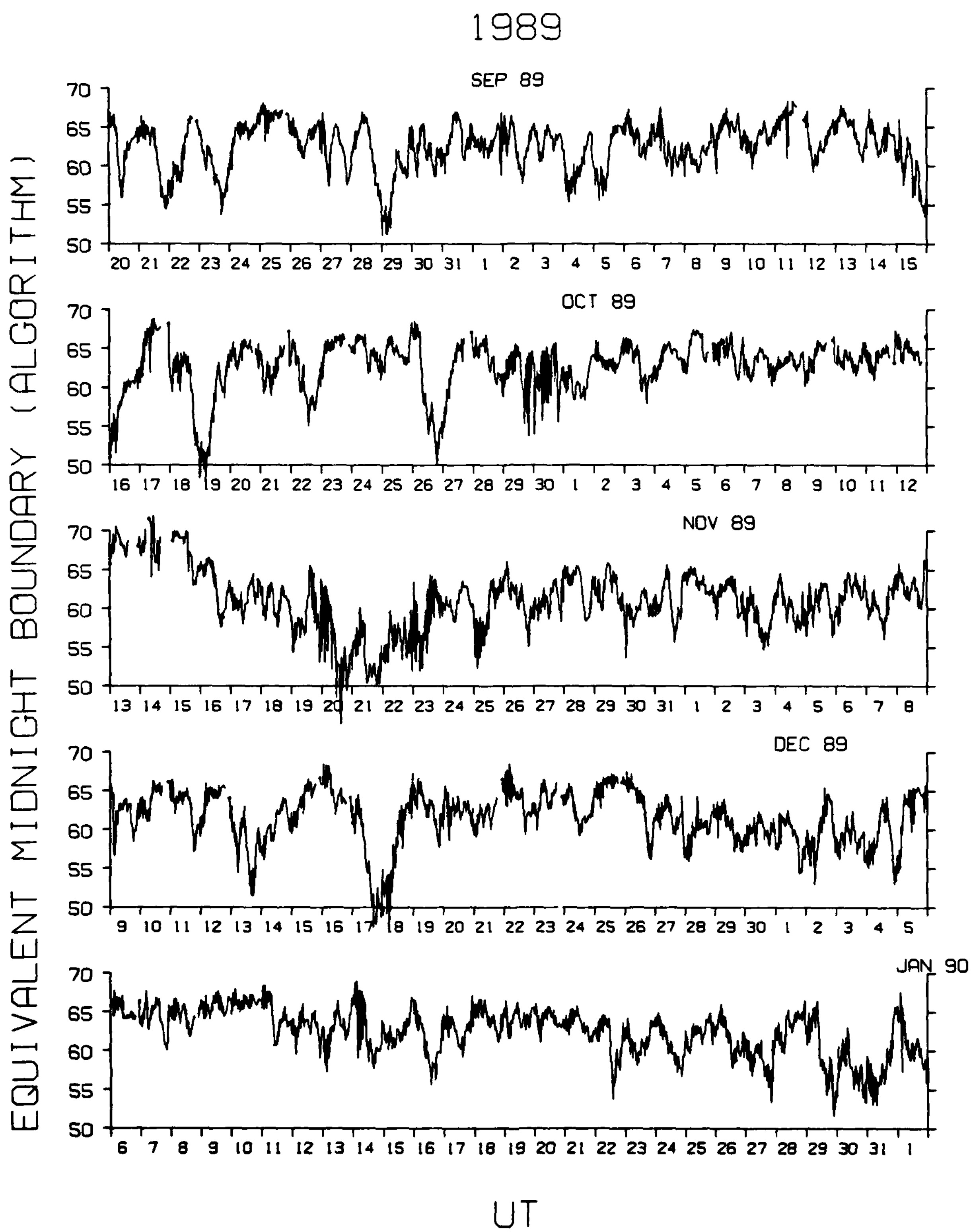
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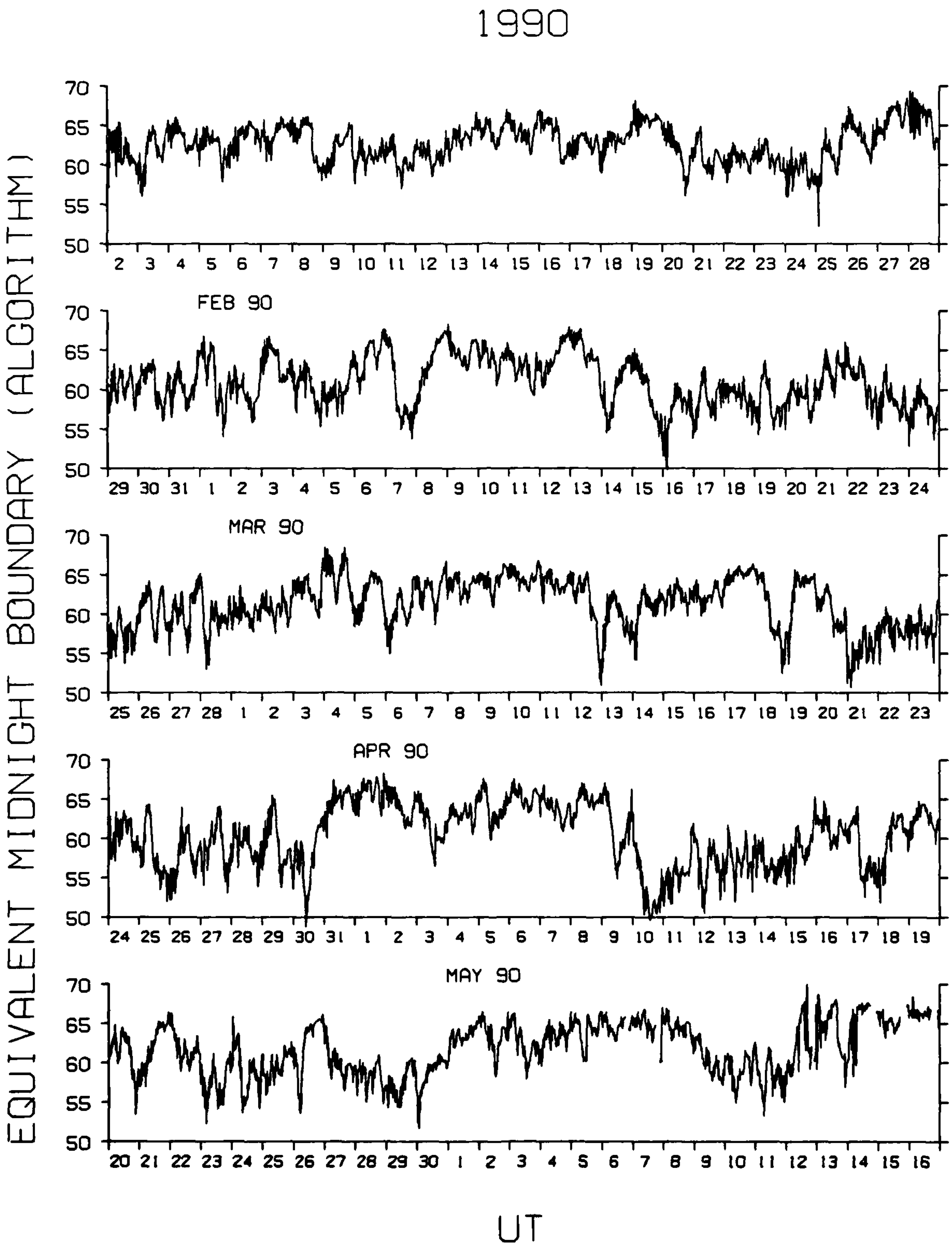
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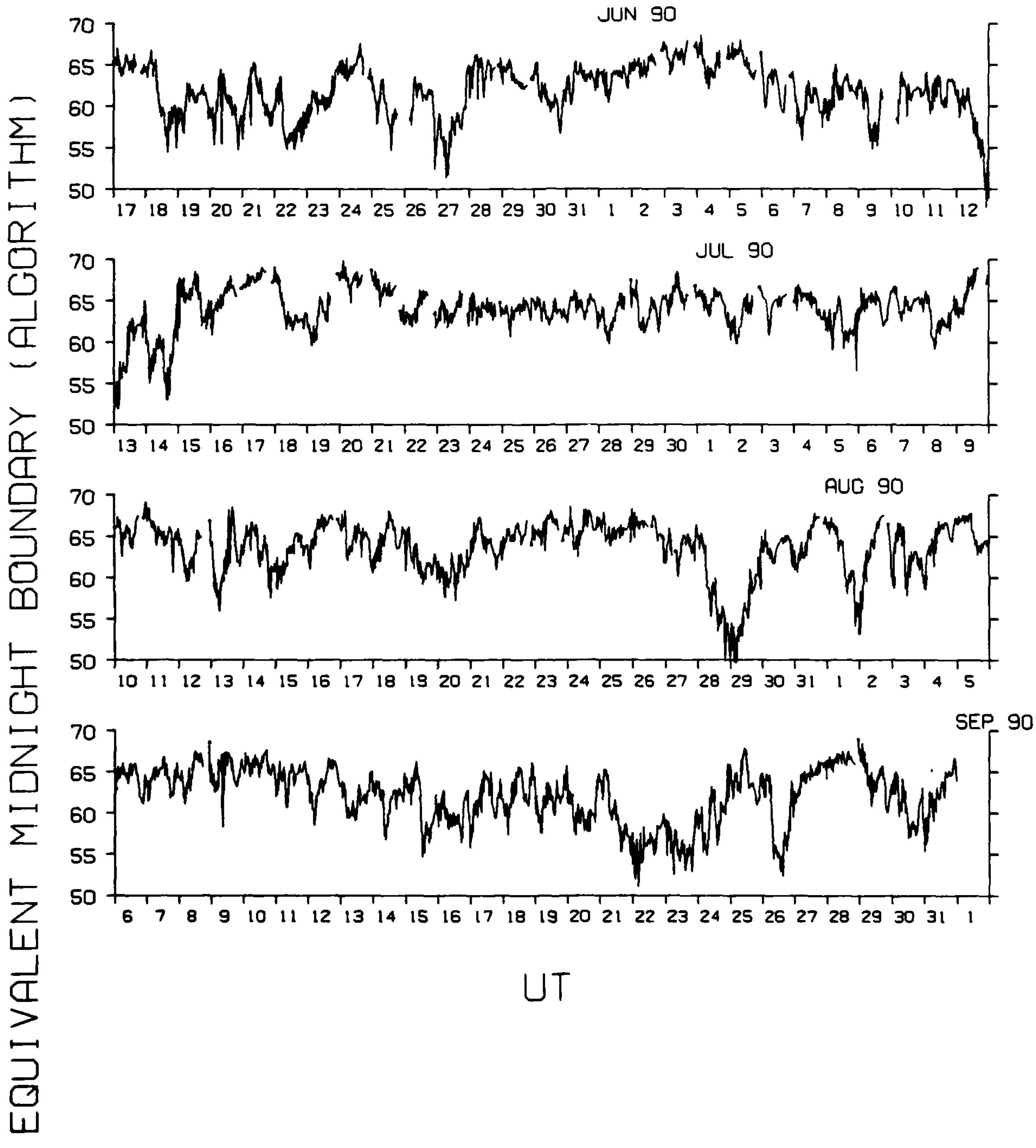

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6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1
EQUIVALENT MIDNIGHT BOUNDARY (ALGORITHM)
UT

APPENDIX A

ACCESSING THE CRRES README FILES FOR AURORAL BOUNDARY INDEX

The following steps will allow you to view, copy or type a boundary file to your personal VAX by way of SPAN:

1. Log onto your VAX

2. View files in a CRRES subdirectory using the following:

   DIR AFGLSC::USER3:[PH.CRRES.README.ACTIVITY]

3. To COPY a file to your account, enter:

   COPY AFGLSC::USER3:[PH.CRRES.README.ACTIVITY]filename yourfile

4. To TYPE a file to your screen, enter:

   TYPE AFGLSC::USER3:[PH.CRRES.README.ACTIVITY]filename

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1. Feldstein, Y.I. and Yu.I. Galperin, The auroral luminosity structure in the high-latitude upper atmosphere: its dynamics and relationship to the large-scale structure of the Earth's magnetosphere, *Rev. Geophys.*, 23:217, (1985)

2. Gussenhoven, M.S. D.A. Hardy and W.J. Burke, DMSP/F2 electron observations of equatorward auroral boundaries and their relationship to magnetospheric electric fields, *J. Geophys. Res.*, 86:768, (1981)

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4. Gussenhoven, M.S. D.A. Hardy, and N. Heinemann, Systematics of the equatorward diffuse auroral boundary, *J. Geophys. Res.*, 88:5692, (1983)

5. Schumaker, T.L., D.A. Hardy, S. Moran, A. Huber, J. McGarity and J. Pantazis, *Precipitating Ion and Electron Detectors (SSJ/4) for the Block 5D/Flight 8 DMSP Satellite*, AFGL-TR-88-0030, Air Force Geophysics Laboratory, Hanscom AFB, Mass., (1988). ADA203990